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ABSTRACT

Thermal power plants contribute to a tune of about 50% of electric energy generation in India. A large volume of coal ash (pond ash and fly ash) is produced by them. Pond ash bricks may be preferred to conventional clay bricks. By this way, natural clay is not over-exploited as well as dumping of coal ash is avoided. Pond ash brick is made with coal ash (pond ash and fly ash), lime, gypsum and stone dust. Attempt has been made to find out the optimal proportion of coal ash in the manufacture of pond ash bricks. Standard experiments to determine various mechanical properties such as compressive strength, weight density, water absorption and durability properties such as chemical characteristics, Initial Rate of Absorption (IRA) and sorptivity have been conducted. In this paper, mechanical properties (compressive strength, water absorption and weight density) of pond ash bricks are presented. Morphology and chemical composition of pond ash, fly ash and pond ash brick have been studied through Scan Electron Microscopy (SEM), Energy Dispersive X-ray Spectrometry (EDS) and X-Ray Diffraction (XRD). Durability properties such as chemical characteristics, IRA and sorptivity are found out from experiments in respect of pond ash bricks, fly ash bricks and clay bricks and are compared and presented.

Key Words: pond ash bricks, SEM-EDS, compressive strength, water absorption.

1. INTRODUCTION

Conventional clay bricks are made by making use of clay, mined from top clay soil, as the prime ingredient. Precious top clay soil is overexploited. This leads to soil erosion and development of wastelands. Thermal power plants produce a large volume of coal ash (pond ash and fly ash). Safe disposal of coal ash is a serious concern in respect of environment protection. In order to minimize over-exploitation of clay soil and consequent soil erosion, and to make use of the coal ash in a productive way, pond ash bricks consisting of coal ash (pond ash and fly ash) are manufactured and promoted. Recent researches have paved way for improving the quality of pond ash bricks. Through experimental studies it has been found that pond ash bricks possess appreciable compressive strength. Scanning electron microscopy (SEM) and energy dispersive X-ray spectrometry (EDS) have been conducted to characterize the morphology of pond bricks and to determine the chemical phases of fly ash and pond ash. EDS has revealed that the elemental concentrations of pond ash bricks are consistent with ICP Optical Emission Spectrometry (ICP-OES) and X-ray diffraction data. Test to determine the initial rate of absorption (IRA) and sorptivity of the three types of bricks has been conducted as per American Society for Testing and Materials code (ASTM C 67). IRA values are helpful to choose the best combination of mortar and brick type so as to achieve good bonding. High IRA in bricks induces shrinkage cracks and the compressive strength of the bond gets reduced. In this paper, mechanical properties (compressive strength, water absorption and weight density) of pond ash bricks are presented. Durability properties such as chemical characteristics, IRA and sorptivity are found out from experiments in respect of pond ash bricks, fly ash bricks and clay bricks and are compared and presented.

2. LITERATURE REVIEW

Larsen et al (1990) investigated the influence of sodium chloride on thermal expansion and hygroscopic shrinkage of both modern and medieval bricks. The study concluded that shrinkage of bricks contaminated with sodium chloride was 70 times higher than the non-contaminated bricks. A number of innovative alternative building materials and low cost construction techniques have been developed through research efforts during the last three to four decades. The results satisfy functional as well as specification requirements of conventional materials and techniques and provide an opportunity for bringing down the construction cost (Daayal, 1995). An experimental study on surface absorption by masonry brick units was carried out by M. M. Reda Taha et al (2001). The sorptivity value of bricks is a reliable, reproducible, engineering measurement for predicting the surface absorption performance of brick units. Piyush Kant Pandey and Raj Kumar Agarwal (2002) attempted to devise ways for utilizing mixed pond ash from integrated steel plants for manufacturing mixed ash clay bricks. The researchers concluded that the use of mixed pond ash in the range of 40-50% remaining being clay provided a very viable option for consumption of huge quantities of fly ash. In addition to superior conventional properties, bricks made up of fly ash and clay have the advantages of bearing the usual red colour, which enhances the acceptance of the users (Das, 2005). Bucea et al (2005) studied the effects of sodium chloride and sodium sulphate on brick masonry. Chloride solution of 14 % by weight of volume and sulphate solution of 6.2 % by weight of volume were added as per guidelines by AS4456.10. Due to crystallization of sodium chloride and sodium sulphate on the mortar, it became soft. Mehmet Tanriverdi (2006) investigated the leachability of toxic elements contained in stream autoclaved fly ash lime bricks. It was concluded that fly ash lime bricks could be used in buildings exposed to weathering. Fly ash bricks were environmentally sound with respect to solubility of toxic elements. Ritwik Sarkar et al (2007) made an attempt to optimize the ratio of pond ash or fly ash to clay which can be utilized in the brick manufacturing process without sacrificing the consistency in the quality of the products. Pond ash with high proportion of coarse particles may be incorporated up to 40 % without affecting the quality of the bricks. Utilization of coal ash in brick manufacturing can greatly reduce the need for dumping the ash in landfills or ash depots. Hakan Cengizler (2009) conducted toxic elements leachability tests on light weight fly ash bricks. Fe, Ni and Mn concentrations were found to be higher than those allowed in the drinking water standards of World Health Organization (WHO) and Turkish Standards Institute (TSE). Arumugam K. et al (2011) studied the properties and use of pond ash as fine aggregate in concrete. Addition of pond ash up to 20 % as fine aggregate replacing sand in concrete increases the split tensile strength and flexural strength of the concrete. Freeda Christy C. and Tensing D. (2011) conducted experiments on fly ash bricks and conventional bricks. The study concluded that thermal power plant byproduct fly ash could be used as a component of greener building material. Fly ash brick is cost effective, environment friendly and has better physical properties than conventional clay bricks. Tabin Rushad and Duggal S. K. (2011) conducted experimental investigations on the properties of lime–soil-fly ash bricks. Lime-fly ash (40:60) bricks satisfy the criteria of Class 3.5 in respect of both strength and water absorption capacity. Akhtar J. N. and Alam J. (2011) studied the properties of bricks with total replacement of clay by fly ash mixed with different materials. The study concluded that natural clay could be replaced by fly ash obtained from thermal power plants in the manufacturing of fly ash bricks.

3. EXPERIMENTAL PROCEDURE

Fly ash, pond ash, gypsum, lime and stone dust have been used for casting 450 specimens of pond ash bricks of size 230 mm x 110 mm x 75 mm. The bricks have been moulded under pressure of 160 kg/cm^2 and cured for 15 days. Various combinations of mix proportions of the ingredient have been adopted (Table 1).

Table 1 Mix combinations of various mixes

Mixes / Material	M1	M2	M3	M4
	percentage			
Fly ash	35	35	35	35
Stone dust	20	20	20	20
Gypsum	5	5	5	5
Pond ash	22	24	26	28
Lime	18	16	14	12

3.1 Microstructure of fly ash and pond ash

Scanning electron microscopy (SEM) micrographs of the fly ash and pond ash appear in Figures 1(a) and 1(b).

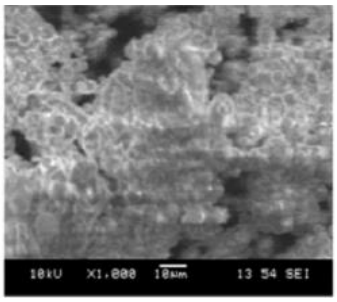


Figure 1(a)
SEM Analysis of Flyash

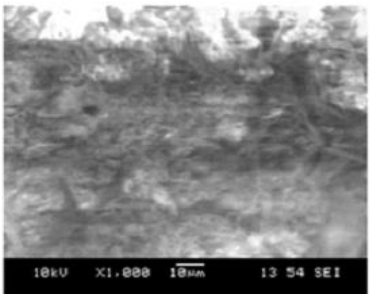


Figure 1(b)
SEM Analysis of Pondash

The fly ash particles consist of very fine grained, amorphous and agglomerate materials varying in size from 10 μm to 50 μm. They exhibit inhomogeneous structure with a spongy appearance. The elemental constituents of fly ash and pond ash have been studied by energy dispersive X-ray spectrometry (EDS) analysis. The pond ash particles are densely packed, irregular in shape, vary in size from 10 μm to 50 μm and exhibit fully closed, honey-combing structure. The EDS analysis graphs pertaining to fly ash and pond ash appear in Figures 2(a) and 2(b).

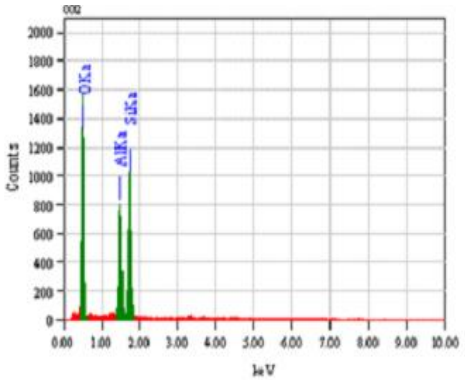


Figure 2(a)
EDS Analysis of Fly ash

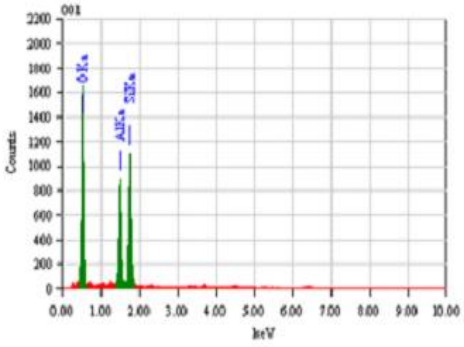


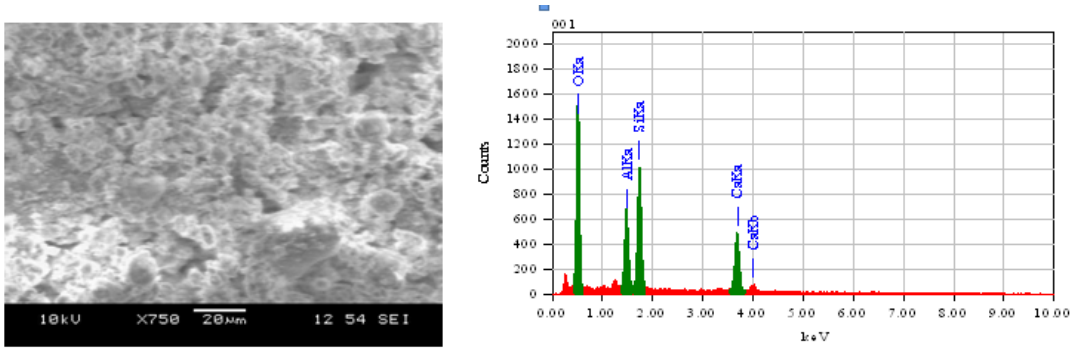
Figure 2(b)
EDS Analysis of Pond ash

Based on the counts value of the element, in the graphs, the peaks are designated as first, second, third and so on in the descending order. The first peak bears highest counts and the lowest peak shows lowest counts. In fly ash, the Al and Si content are

lesser than O. The masses of O, Al and Si elements are 50.98 %, 19.52 % and 29.51% respectively. In pond ash, the masses of O, Al and Si element are 51.01%, 19.23% and 29.76% respectively.

3.2 Microstructure of pond ash bricks

The SEM micrographs and EDS analysis graphs depicting the structure and mineral phases of pond ash bricks are presented in Figures 3(a) and 3(b). The particle size of pond ash brick varies from 1 µm to 100 µm. The brick powder particles are spherical in shape, fused together and homogeneous in constitution. The coal ash bricks contain 80.48 % of non-calcium oxides of SiO_2 and Al_2O_3 and 19.52% of CaO.



a) SEM Micrograph b) EDS Spectrum.

Fig. 3 SEM/EDS Analyses of Brick Powder

3.3 Mineralogy and Chemical composition of materials

The XRD analysis was used to confirm the crystalline character of the phases formed during the alkali activations. Figure 4(a) shows the XRD analysis of fly ash sample.

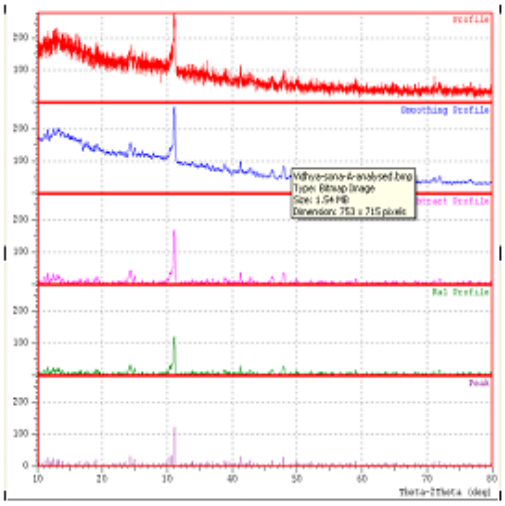


Figure 4(a) XRD of Fly ash

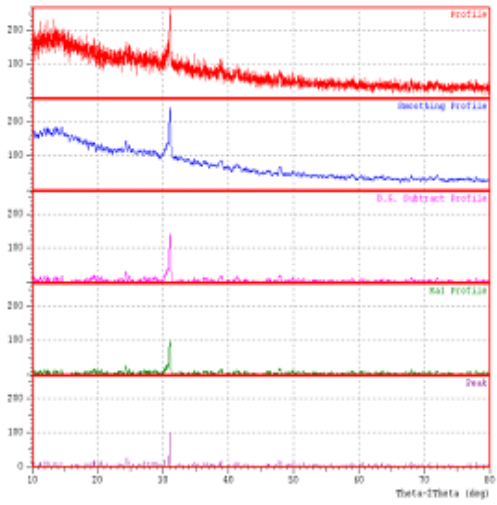


Figure 4(b) XRD of Pond ash

The fly ash is essentially a vitreous material, consisting of a series of majority crystalline phases such as quartz (SiO_2) and alundum (Al_2O_3). The X-ray diffraction patterns for the fly ash material indicate amorphous (glassy) nature. It is also apparent from the characteristic peak typical of the closely packed frame work of atoms and molecules. The mass percentage of alundum is 36.34% and for quartz it is 63.66%. The fly ash samples are less porous in texture and the activation process is slow. Figure 4(b) shows the XRD analysis for pond ash material. The pond ash is a substantial material. It contains a series of minority crystalline phases such as quartz, alundum and FeO. The XRD analysis of the pond ash material reveals that it is spongy and has honey-comb structure. The pond ash consists of spherical metallic particles. The mass percentage of quartz is 34.29%, for alundum it is 64.28% and for FeO it is 1.43%.

4. TESTING OF POND ASH BRICKS

Figure 5 shows the experimental setup for compressive strength test. The compressive strength of brick is given as the ratio of maximum failure load to the area of the bed faces in N/mm^2. The compressive strength of pond ash brick has been determined following IS 3495:1992 (Part 1), and by using compressive testing machine.

Figure 5 Experimental setup for compressive strength test

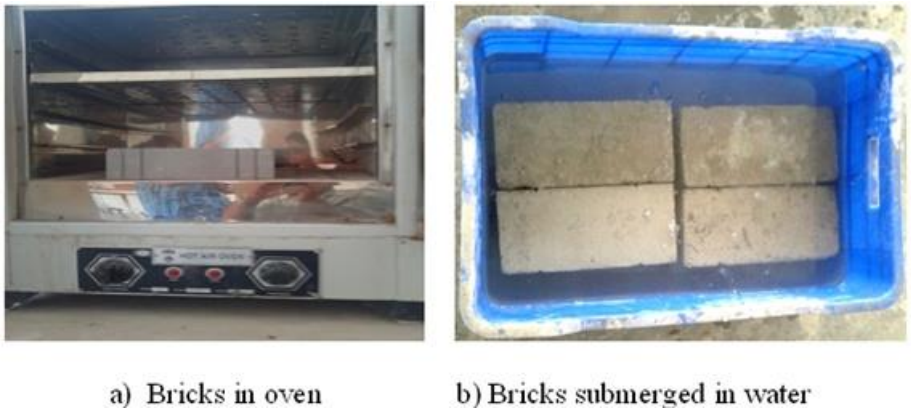


Figure 6 Water absorption test

The experimental setup for water absorption test appears in Figure 6. The water absorption capacity of brick is determined as the ratio of change in weight of the brick after immersion in water for one day to the initial (original) weight of the brick. Water absorption test has been performed on coal ash brick as per IS code 3495:1992 (Part 2). Weight density of pond ash brick has been determined by weight of the brick to the volume of the brick and given in kN/m^3. Efflorescence test has been performed in pond ash brick as per IS code 3495:1992 (Part 3). The absence of grey or white deposit on the brick surface indicates absence of soluble salts.

Durability test:

Chemical test has been carried out on pond ash brick, fly ash brick and clay brick. The bricks have been subjected to various aggressive chemical environments. They have been cured in three kinds of water, viz, potable water with 5 % of sodium sulphate, potable water with 5 % of sodium chloride and sea water. The weight and strength of the bricks have been noted after a period of 7, 21, 28, 56 and 90 days of immersion. Compressive strength and weight loss of the bricks have been noted.

Initial rate of absorption:

Initial rate of absorption (IRA) test has been conducted on the brick specimens by following the procedures given in ASTM C 67. Figure 7 shows the IRA test setup. A transparent pan is kept under room temperature.

Figure 7 IRA test for clay brick, pond ash brick and fly ash brick

A supporting device is placed at the bottom of the pan. Above the top of the supporting device, a column of 1-3 mm height of potable water is kept. The top bed surface of the brick is covered with plastic sheet and bottom bed surface is kept in contact with water. The other faces of the brick are sealed with bitumen. The bottom bed surface of the brick is placed inside the pan resting on the supporting device. This test shows that water flows in uni direction. IRA for the three types of brick has been measured for a period of 1-minute and 2-minute. It is calculated by using the following formula:

$$I = \frac{m}{(a \times \rho)}$$

ρ - Density of the water in g/mm^{3,}
m- Change in weight in grams
a – area of the bed surface in mm^2

Sorptivity test:

Sorptivity test has been conducted as per ASTM C 67. Sorptivity test setup is similar to that of initial rate of absorption test. The change of the weight in the brick specimens has been calculated at given time intervals as per ASTM C 67. The values have been plotted in the graph by assigning time (sec$^{1/2}$) in x axis and absorption values in y axis. Sorptivity value of brick specimen has been calculated from the graph by using the following formula:

$$S = \frac{i}{(t)^{1/2}}$$

S - sorptivity value
i – absorption in mm
t – time in secs.

5. RESULTS AND DISCUSSIONS

The values of compressive strength, water absorption and weight density for pond ash bricks appear in Table 2.

Table 2 Test results for pond ash bricks

Mixes	Compressive strength in N/mm^2	Water absorption in %	Weight density in kN/m^3
M1	8.7	8.85	15.62
M2	8.2	8.65	15.21
M3	7.6	8.60	14.78
M4	7.2	8.30	14.56

5.1 Test results for compressive strength

The pond ash bricks prepared with M1, M2, M3 and M4 mix combinations possess compressive strength of 8.7 N/mm^2, 8.27 N/mm^2, 7.67 N/mm^2 and 7.27 N/mm^2 respectively. As per IS code 12894:2002 and based on compressive strength, M4 pond ash bricks pertain to Class designation 5 and M1, M2 and M3 pond ash brick belong to Class designation 7.5. The compressive strength test results indicate that the compressive strength of pond ash bricks gets increased with increase in lime content.

5.2 Test result of water absorption

The water absorption values for the pond ash bricks made with M1, M2, M3 and M4 mix combinations are 8.85 %, 8.65 %, 8.6 % and 8.3 % respectively. The pond ash percentage in these four mixes (M1, M2, M3 and M4) is 20, 22, 24 and 26 respectively. The IS code 3495:1992 (Part 2) prescribes that the water absorption value of brick should be less than 20 % for class 12.5 and 15 % for higher classes. Water absorption is less than 15 % for the pond ash bricks of mix combinations M1, M2, M3 and M4. It is found that the water absorption gets increased with increase in pond ash proportion. Acting as a filler material, pond ash reduces the volume of pores in pond ash bricks. It is also noted that with increase in pond ash content, the durability of pond ash gets increased.

5.3 Test result for weight density

The weight density values for four mixes have been determined. The weight density values of pond ash bricks are 15.62 kN/m^3, 15.21 kN/m^3, 14.78 kN/m^3 and 14.56 kN/m^3 for pond ash proportions 20, 22, 24 and 26 respectively. The unit weight of the pond ash brick gets reduced with increase in pond ash percentage. Since self weight of the wall gets decreased with the usage of pond ash brick, the need for steel reinforcement to be provided also gets minimised. It reduces the cost of the construction of the building.

5.4 Test results for efflorescence

All the brick specimens have shown neither grey nor white deposits on the surface indicating the absence of soluble salts in the bricks.

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5.5. Test results for durability

5.5.1 Chemical test

Table 3 shows the chemical test performance for the various brick.

Table 3 Durability studies on clay brick, pond ash brick and fly ash brick

Brick	Sodium sulphate solution		Sodium chloride solution		Sea water	
	Weight gain in %	Strength loss in %	Weight gain in %	Strength loss in %	Weight gain in %	Strength loss in %
Clay	15	7.6	14.8	6.5	14.2	8.2
Pond ash	9.8	14.2	9.7	10.8	8.3	5.2
Fly ash	0.2	14.5	10	11.4	9.4	15.7

After 90 days of immersion in sodium sulphate solution, pond ash bricks have shown 2.1 % higher compressive strength than that of fly ash bricks. Clay bricks have attained 15 % gain in weight. During the period of immersion in sodium chloride solution, the pond ash and fly ash bricks show increase in their compressive strength up to 28 days of immersion; but, after that, they show decrease in their compressive strength up to 90 days of immersion. The compressive strength of pond ash bricks is 5.5 % greater than that of fly ash bricks, after immersion in sodium chloride solution for 90 days. The weight loss in all types of brick submerged in sea water is higher than that obtained after submergence in sodium sulphate solution and sodium chloride solution for 90 days. Sodium sulphate solution in potable water reacts strongly with CaO (lime) in fly ash brick, hence the loss of compressive strength in fly ash brick is higher than that of pond ash brick.

5.5.2 Test results for initial rate of absorption (IRA)

IRA values for 1-minute time in respect of clay brick, pond ash brick and fly ash brick are 0.740, 0.328 and 0.439 gm/cm^2 respectively. For 1-minute time, the IRA value of pond ash brick is 50 % and 13 % lower than the IRA value of clay brick and fly ash brick respectively. For 2-minute time, the IRA value of pond ash brick is 51 % and 24 % lower than the IRA value of clay brick and fly ash brick respectively. Thus, the IRA value of pond ash brick is lower than that of clay brick and fly ash brick for 1-minute and 2-minute time periods. It is observed that the IRA value of pond ash brick is lesser due to lesser water absorption imparted by lower porosity.

5.5.3 Test results for sorptivity

Figures 8, 9 and 10 show the sorptivity plot for (absorption vs time$^{1/2}$) for masonry brick units made up of clay bricks, pond ash bricks and fly ash bricks.

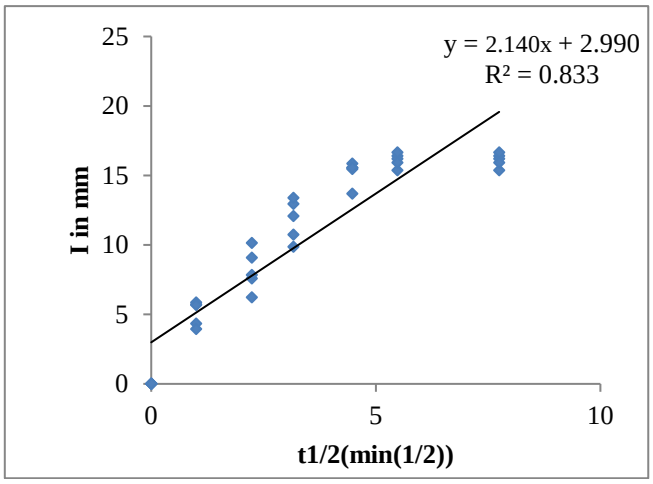

Figure 8 Absorption vs time^{½} for clay brick

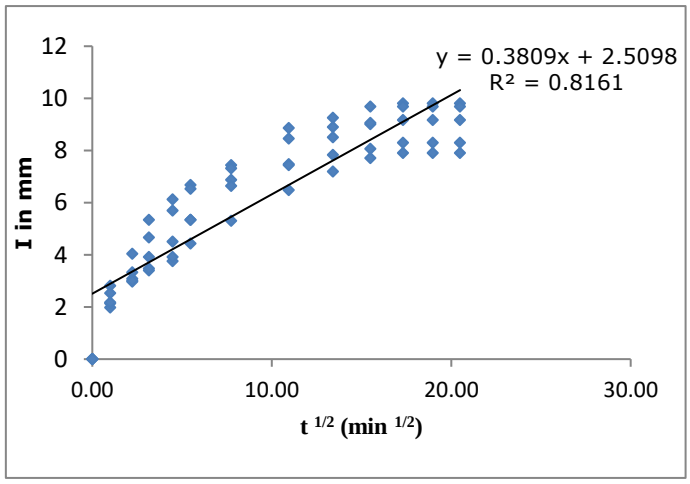

Figure 9 Absorption vs time^{½} for pond ash brick

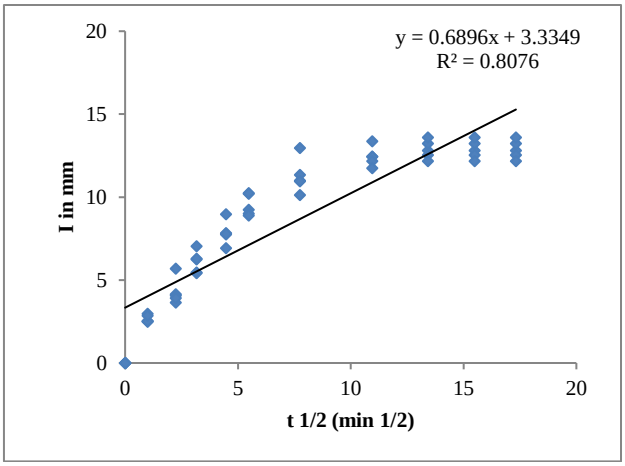

Figure 10 Absorption vs time^{½} for fly ash brick

The clay bricks, pond ash bricks and fly ash bricks become saturated within 60, 42, and 320 minutes respectively during the experiments. The curves flatten off. The following equations have been arrived at from the plot of absorption values and square root of time interval.

For clay brick, $i = 2.140(t^{0.5}) + 2.990$
For pond ash brick, $i = 0.380(t^{0.5}) + 2.509$
For fly ash brick, $i = 0.689(t^{0.5}) + 3.334$

Consolidated sorptivity values for clay bricks, pond ash bricks and fly ash bricks are presented in Table 4.

Table 4 Sorptivity-average values of bricks

Clay brick		Pond ash brick		Fly ash brick	
Sorptivity	**(min)**	**Sorptivity**	**(min)**	**Sorptivity**	**(min)**
2.14	60	0.380	420	0.689	300

Clay bricks show a sorptivity value of 2.14 at 60 minutes. Pond ash bricks exhibit a sorptivity value of 0.38 at 420 minutes. Fly ash bricks attain a sorpitivity value of 0.689 at 300 minutes. The water absorption value of pond ash brick is less than 10 % which is lesser than that of clay bricks and fly ash bricks. Since the sorptivity value of pond ash bricks is less, the initial rate of absorption value of pond ash bricks is also less. Sorptivity test describes the absorption capacity of brick units, taking the interaction between mortar and brick at critical point. Durability of masonry unit becomes better when pond ash bricks are used. Pond ash bricks possess lesser sorptivity values than that of clay bricks and fly ash bricks. Hence the durability of masonry units constructed with pond ash bricks becomes better.

6. CONCLUSION

Based on the results presented in this paper, the following conclusions are drawn:

a) The compressive strength of pond ash bricks varies from 7.6 to 8.7 N/mm^2. Pond ash bricks made with mix combinations M1, M2 and M3 fall under IS code 12894:2002 Class 7.5 designation.
b) With increase in pond ash percentage, in bricks, the water absorption capacity of the bricks is reduced. Due to lesser amount of water absorption, lesser quantity of water penetrates and seepage of water through bricks is minimised.
c) Water absorption is directly proportional to porosity. Pond ash bricks have lower porosity. This improves their durability.
d) With increase in pond ash percentage, the weight and weight density of pond ash brick get reduced. Since, self weight of the wall gets decreased with the usage of pond ash brick, the need for steel reinforcement to be provided also gets minimised. It reduces the cost of the construction of the building.
e) IRA value of pond ash brick is lesser than that of clay brick and fly ash brick. This is due to lesser water absorption imparted by lower porosity.

f) Pond ash bricks possess lesser sorptivity values than that of clay bricks and fly ash bricks. Hence the durability of masonry units constructed with pond ash bricks becomes better.

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